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Influence of Red Alder on Chemical Properties of a Clay Loam Soil in Western Washington

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Abstract

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Chemical characteristics of mineral soil beneath red alder (*Alnus rubra* Bong.) stands of various ages were studied. Total nitrogen (N) of the 0- to 20-centimeter (0- to 8-inch) soil layer increased with stand age, and pH of both the 0- to 20-centimeter and 20- to 50-centimeter (8- to 20-inch) layers decreased with stand age. Contents of some mineral nutrients accumulated with N in one or the other soil layers. Conversely, exchangeable calcium and magnesium decreased substantially in the 0- to 20-centimeter layer as total N increased and pH decreased. Authors suggest monitoring base status of alder soils and testing base-containing fertilizers in red alder stands.

Keywords: Soil properties (chemical), red alder, *Alnus rubra,* nitrogen accretion, soil pH, mineral soils.

Summary

Chemical characteristics of the 0- to 20-centimeter (0- to 8-inch) and 20- to 50-centimeter (8- to 20-inch) layers of mineral soil under red alder (*Alnus rubra* Bong.) stands, age 0 to 45 years, were studied on the same soil type. The influence of alder on chemical properties was assessed by correlation and linear regression analyses of: (1) total nitrogen (N) content, pH, and mineral nutrient contents with stand age; and (2) mineral nutrient content with total N content and pH. Results were considered significant at $P \leq 0.15$. Total N of the 0- to 20-centimeter layer was positively correlated, and pH of both soil layers was negatively correlated with stand age. None of the mineral nutrients were significantly related to stand age, but many of them were significantly correlated with total N and/or pH. Thus, as N accumulated, total sulfur, exchangeable potassium, and extractable iron, copper, and zinc increased in one or the other soil layers. In addition, exchangeable calcium and magnesium decreased in the 0- to 20-centimeter layer as total N increased and pH decreased. Red alder can enrich N content of forest soils. Amounts of some other nutrients may also be increased in the rooting zone through redistribution, but contents of some important bases may be reduced. Monitoring the base status of alder soils and evaluating the response of red alder stands to base-containing fertilizers are suggested.

Introduction

Red alder (*Alnus rubra* Bong.) is the major hardwood tree species in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region of the Pacific Northwest. Alder is often considered to be a site-improving species. It is well known for its ability to increase total nitrogen (N) and organic matter of the soil (Bormann and DeBell 1981, DeBell and Radwan 1979, Tarrant and Miller 1963). Accordingly, the species has been recommended for planting on surface mine spoils where low soil fertility is a problem in establishing vegetation. In addition, alder has been suggested as a biological source of N for use in mixtures or crop rotations with conifers.

Effects of alder on soil reaction and levels of nutrients other than N have also been reported, but results have not been consistent. Tarrant (1961), for example, reported that potassium (K), calcium (Ca), and magnesium (Mg) contents of the upper 3 inches (7.6 cm) of soil (including the forest floor) in the Cascade Range of Washington were higher under a mixed stand of red alder and Douglas-fir than under a pure stand of Douglas-fir, although not significantly so. Phosphorus (P) content of the soil did not differ between these stands, and differences in soil pH were not significant. Bollen and others (1967) and Franklin and others (1968) indicated that pH and contents of exchangeable Ca and Mg, and the sum of exchangeable bases were distinctly lower in soil under red alder than in soil under conifers in the Oregon Coast Ranges. There were no significant differences between soils in amounts of exchangeable K, exchangeable sodium (Na), or extractable P, and only small differences in sulfate and available boron (B). Van Cleve and Viereck (1972), working in 0- to 20-year-old thinleaf alder (*Alnus tenuifolia* Nutt.) ecosystems established on flood plain soils in Alaska, reported that pH gradually decreased through age 20. Concentrations of exchangeable K, Ca, Mg, and manganese (Mn), and total P increased markedly during the first 5 years. Little change occurred thereafter except during the last 5 years when K increased and Mg decreased significantly.

The purpose of this investigation was to elaborate on the effects of red alder on N content and pH of the soil and to assess the influence of the species on other essential nutrients in mineral soil.

Materials and Methods

Study Area and Selected Alder Stands

The study area is in the Capitol Forest, southwest of Olympia, Washington, on land administered by the State of Washington Department of Natural Resources. Soils are of the Boistfort series and are very deep, well-drained clay loams formed on Eocene basalt in a mild, wet coastal climate. Overstory vegetation consists primarily of pure and mixed stands of Douglas-fir and red alder. Site index averages about 40 and 30 m, respectively, at 50 years for Douglas-fir and red alder (McMurphy and Anderson 1968). Understory species include swordfern (*Polystichum munitum* (Kaulf.) Presl.), salmonberry (*Rubus spectabilis* Pursh), salal (*Gaultheria shallon* Pursh), vine maple (*Acer circinatum* Pursh), elderberry (*Sambucus* spp.), and Oregongrape (*Berberis aquifolium* Pursh).

Eight stands, similar in soil, aspect, and slope, were selected. Stands were of sufficient size (> 1 ha) to minimize edge effects and, with one exception, were located within an area 2.5 km in radius. Seven of the stands were uniformly stocked with red alder and ranged in age from 9 to 45 years. The eighth stand consisted of the typical forest cover in the general area surrounding the alder stands and was occupied by 40- to 50-year-old Douglas-fir. Mineral soil layers of that stand were assumed to represent the general base-line condition (age 0) for new red alder stands established in the area.

The number of stands used in this study is small, but we were unable to locate additional appropriate stands on the same soil type in the same area.

Sampling and Processing of Mineral Soil

Sampling was done in June 1979. Two perpendicular, 10-m transects were laid out at each of the seven red alder sites, and soil was sampled at equal intervals along the transects. After the forest floor was removed, two layers of mineral soil, 0 to 20 cm and 20 to 50 cm deep, were collected with an aluminum tube. At each site, 20 samples (347 cm^3 each) were collected from the upper soil layer and 8 samples (521 cm^3 each) from the lower soil layer. Soil was composited by layer and site, and samples were airdried at room temperature. Live roots, charcoal fragments, and rocks were removed and discarded. Soil aggregates were crushed with a rolling pin, and the soil was passed through a 2-mm sieve. The <2-mm soil was weighed, and subsamples were dried to constant weight at 65 °C to determine moisture content and to prepare the soil for chemical analysis. Subsamples of this soil were dried further at 105 °C, and the ovendry weight of the <2-mm soil per hectare was calculated for each layer.

Mineral soil was sampled as described above at four points in each of four locations within the eighth (Douglas-fir) stand and composited to represent the baseline condition.

Chemical Analysis

All chemical analyses were carried out at least in duplicate, and reults were calculated on an ovendry-weight basis.

Soil pH was determined on 1:1 soil-water suspensions by glass electrode. Total N was estimated by the semimicro-Kjeldahl method (Bremner 1965). Minerals determined and analytical methods used were as follows: extractable P (extracted with Bray-Kurtz solution 2 (Bray and Kurtz 1945)) by the molybdenum blue technique (Chapman and Pratt 1961); exchangeable K, Ca, and Mg (extracted with neutral 1 N NH_4OAC), and extractable iron (Fe), Mn, copper (Cu), and zinc (Zn) (extracted with diethylene triaminepentaacetic acid (DTPA) according to Lindsay and Norvell (1978)) by standard atomic absorption spectrophotometric methods; and total sulfur (S) and sulfate S (extracted with $Ca(H_2PO_4)_2$ (Fox and others 1964)) by the turbidimetric method of Butters and Chenery (1959).

Statistical Analysis

Correlation analysis and linear regression procedures were used to evaluate relationships of: (a) total N content, pH, and mineral nutrient contents to stand age; and (b) mineral nutrient contents to total N content or soil pH. Relationships were considered significant at $P \leq 0.15$, a level of probability considered appropriate in view of inherent soil heterogeneity and the number of stands used in the study.

Results

Table 1—Chemical characteristics of mineral soil beneath red alder stands in western Washington[1]

Stand age	pH	N	P	K	Ca	Mg	S	SO_4-S	Fe	Mn	Cu	Zn
Years						*Kilograms/hectare*						
						0- to 20-cm layer						
0	5.52	3030	239	468	1570	296	295	50	121	82	2.4	6.0
9	5.24	3390	240	324	564	74	370	76	126	49	1.5	9.2
18	5.32	2890	58	355	1230	329	270	18	95	37	2.5	7.9
28	5.35	3110	342	432	1310	228	240	0	113	57	2.1	12.7
31	4.90	3330	73	293	568	110	311	27	89	54	1.6	4.4
38	5.30	3590	200	442	1140	236	336	0	117	75	2.7	9.0
42	5.30	3170	266	436	1050	197	270	0	120	67	2.5	9.5
45	4.85	4000	187	294	400	58	386	50	108	44	2.3	24.3
						20- to 50-cm layer						
0	5.45	2550	165	357	1060	251	441	214	112	69	2.2	3.9
9	5.25	4000	262	373	429	67	611	240	116	33	1.8	13.3
18	5.44	3390	48	359	1580	543	424	133	121	39	2.4	14.5
28	5.40	3590	323	483	1380	290	428	174	127	50	2.5	24.8
31	5.03	2330	76	277	443	91	402	140	54	35	.8	2.6
38	5.25	3800	192	459	1130	235	464	162	124	78	2.9	14.3
42	5.29	3740	283	470	1270	299	481	134	144	72	2.7	16.0
45	5.08	3850	154	435	674	133	784	337	112	59	2.4	11.8

[1] Values are means of 2 determinations each, run on the <2-millimeter fraction of mineral soil. Nitrogen (N) and sulfur (S) values represent total content of each element. Other nutrients were determined in soil solutions obtained by extractions with Bray and Kurtz solution No. 2 (1945) for phosphorus (P); 1N neutral NH_4OAC for potassium (K), calcium (Ca), and magnesium (Mg); $Ca(H_2PO_4)_2$ for SO_4-S; and DTPA for iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn).

The pH of mineral soil averaged 5.2 for the upper layer and 5.3 for the lower layer (table 1). Soil pH was negatively correlated with stand age for both the upper and lower layers (table 2).

Total N in the soil to the 50-cm depth ranged from 5580 kg ha^{-1} at age 0 to 7850 kg ha^{-1} at age 45 years. Concentrations of N in the upper layer were much higher than in the lower layer (0.20 to 0.30 percent vs. 0.13 to 0.18 percent), and average content of N was higher at the surface (166 vs. 113 kg ha^{-1} cm^{-1}). Also, total amounts of N in the upper soil layer, but not in the lower, were significantly related to stand age; nitrogen accumulated at a rate of about 12.8 kg ha^{-1} yr^{-1} in the 0- to 20-cm layer. Total N accumulation to a depth of 50 cm was about 27 kg ha^{-1} yr^{-1}.

Table 2—Correlation coefficients (r) between soil chemical characteristics and stand age[1]

Item	0- to 20-cm layer		20- to 50-cm layer	
	r	P	r	P
pH	-0.58	0.13	-0.57	0.14
Total nitrogen	.58	.13	.36	.38
Extractable phosphorus	-.01	.98	.10	.82
Total sulfur	.12	.78	.29	.48
SO_4-S	-.54	.17	.03	.94
Exchangeable potassium	-.18	.67	.49	.22
Exchangeable calcium	-.42	.31	.02	.95
Exchangeable magnesium	-.36	.38	-.09	.83
Extractable iron	-.23	.59	.08	.84
Extractable manganese	-.14	.74	.33	.43
Extractable copper	.28	.50	.26	.54
Extractable zinc	.52	.18	.29	.48

[1] Correlations are considered significant at $P \leq 0.15$.

Total S trends, especially in the upper layer, were similar to those of total N. Unlike N, however, the average amount of S was slightly higher in the lower layer of soil than in the upper (17 vs. 16 kg ha^{-1} cm^{-1}). In addition, total S of either soil layer was not related to stand age.

Sulfate S was substantially more concentrated in the lower layer than in the upper (average of 6.4 vs. 1.4 kg ha^{-1} cm^{-1}). Extracted P and the bases—K, Ca, Mg, Fe, Mn, Cu, and Zn—did not vary much by layer.

Except for N in the upper layer of mineral soil, contents of other nutrients were not significantly correlated with stand age in either layer ($P>0.15$ in all cases). The correlation of contents of several mineral nutrients with total N or pH of the respective soil layer, however, was significant as was the negative correlation between soil pH and total N (table 3). Exchangeable Ca and Mg contents of the upper layer of mineral soil were both negatively correlated with total N. Linear regression relationships indicate that decreases of 160 kg ha^{-1} exchangeable Ca and 40 kg ha^{-1} exchangeable Mg are associated with each increase of 100 kg ha^{-1} N. Potassium in the lower layer of mineral soil was positively correlated with total N. Contents of exchangeable Ca, Mg, and K in the upper layer were positively correlated with soil pH; a decrease of 0.1 pH unit is associated with decreases of approximately 100 kg ha^{-1} Ca, 60 kg ha^{-1} Mg, and 20 kg ha^{-1} K. Calcium and Mg contents were also strongly correlated with pH in the lower layer. Iron content of the lower layer was positively correlated with both soil pH and total N, and Cu content of that layer was correlated with total N. Zinc contents of both layers were positively correlated with total N. Total S content of the upper layer was positively correlated with total N and negatively correlated with pH.

Table 3—Correlations between chemical characteristisc of mineral soil and total nitrogen (N) or pH[1/]

Correlation	0- to 20-cm layer		20- to 50-cm layer	
	r	P	r	P
Total N vs. pH	-0.71	0.05	0.04	0.93
vs. phosphorus	.01	.98	.53	.17
vs. total sulfur (S)	.83	.01	.55	.16
vs. potassium (K)	-.46	.26	.74	.04
vs. calcium (Ca)	-.72	.04	.14	.74
vs. magnesium (Mg)	-.74	.03	.04	.93
vs. iron (Fe)	.08	.86	.72	.04
vs. manganese (Mn)	-.13	.77	.16	.71
vs. copper (Cu)	-.06	.89	.64	.09
vs. zinc (Zn)	.72	.04	.73	.04
pH vs. phosphorus	.44	.28	.22	.61
vs. total S	-.56	.15	-.46	.26
vs. K	.85	.01	.25	.55
vs. Ca	.89	.003	.77	.02
vs. Mg	.78	.02	.72	.04
vs. Fe	.54	.17	.61	.11
vs. Mn	.53	.17	.18	.67
vs. Cu	.40	.32	.52	.19
vs. Zn	-.46	.23	.38	.36

[1/] Phosphorus, K, Ca, Mg, Fe, Mn, Cu, and Zn values represent extracted content of each element. Correlations are considered significant at $P \leq 0.15$.

Discussion and Conclusions

Of all the chemical soil properties studied, only pH and total N of the upper layer of mineral soil were significantly related to stand age. The decrease in soil pH with age parallels previous findings about red alder (Bollen and others 1967, Bormann and DeBell 1981, Franklin and others 1968), and other alder species (Crocker and Major 1955, Van Cleve and Viereck 1972). Such increases in soil acidity with increasing stand age may be related to litter decomposition and nitrification rates which are greater under alder than under stands of other species (Cole and others 1978).

As expected, N was accumulated in the soil under red alder with highest amounts detected in the 0- to 20-cm layer. Nitrogen accretion rates (27 kg $ha^{-1}yr^{-1}$), however, were lower than many of those indicated in the literature for red alder (Bormann and DeBell 1981, DeBell and Radwan 1979, Newton and others 1968, Tarrant and others 1969) and other alder species (Crocker and Major 1955, Van Cleve and others 1971). These previous reports indicate a range of <40 to >300 kg ha^{-1} annually. Such variation in findings, however, is to be expected and may be ascribed to many factors, especially differences in vigor, composition, age, density, and location of the stand; soil fertility; season of sample collection; and methods of sample collection, preparation, and chemical analysis.

None of the mineral nutrients were significantly related to stand age. Present mineral content of soil layers may be influenced by soil mineralogy, previous stand history, present overstory stocking, and understory composition. It is possible that inherent variation among stands in these unaccounted for characteristics was sufficient to mask relationships, if any, of mineral nutrient properties to stand age.

On the other hand, contents of many of the mineral nutrients were strongly correlated with N content or pH of the mineral soil. Because effects of red alder on N accretion and pH have been consistent in nearly all studies, we believe these variables are indices of the cumulative effects of the species on a site. Thus, as N accumulated, total S, exchangeable K, and extractable Fe, Cu, and Zn increased in at least one soil layer. In addition, exchangeable Ca and Mg decreased significantly with increased soil N and acidity. Regression equations suggest that addition of 500 kg N ha^{-1} to the surface layer via a 40-year saw-log rotation of red alder may be accompanied by decreases of 800 kg ha^{-1} of exchangeable Ca and 200 kg ha^{-1} of exchangeable Mg. Some of these bases will undoubtedly be contained in the alder crop and in the understory vegetation (Turner and others 1976). The remainder will probably be leached to greater depth in the soil profile, stimulated by the rapid decomposition, nitrification, and acidification processes beneath alder stands. Potential decreases and leachings of Ca and/or Mg are consistent with available literature on red alder (Cole and others 1978, Franklin and others 1968) and other alder species (Van Cleve and Viereck 1972). Furthermore, in pot-culture studies, our unpublished data and experiments by others (Hughes and others 1968) show good response of red alder seedlings to some base-containing fertilizers. Still, more information is needed since the importance of such decreases in soil contents of these mineral nutrients is not known; it will probably depend on many factors, including depth of leaching, inherent soil fertility, rate of mineral weathering, and nutrient requirements of alder and other forest tree species.

This study reaffirms the well-established view that red alder can add significant amounts of N to the soil. Alder, like other hardwoods, may also play an important role in soil development by bringing other nutrients to upper soil layers. Such accumulation and redistribution of nutrients could benefit associated or succeeding forest crops. Red alder, however, will also acidify the soil profile and may lead to reductions of Ca and Mg. Such potential negative effects should not be disregarded. Until more information is available, therefore, the base status of soil should be monitored whenever alder is grown for long periods. We also suggest testing nonnitrogenous fertilizers on alder under field conditions. Such information, we believe, is necessary if red alder is to be grown in pure or mixed stands to maximum yield without adverse effects on soil productivity.

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English Equivalents

1 centimeter = 0.3937 inch
1 millimeter = 0.03937 inch
1 hectare = 2.471 acres
1 kilogram per hectare
= 1.1206 pounds per acre
(9/5°C) + 32 = °F

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